

**REMARKS**

**I. Introduction**

In response to the pending Office Action, Applicants have amended the specification and the drawings in accordance with the Examiner's comments set forth in the Office Action. Applicants wish to thank the examiner for his assistance in correcting the specification.

Applicants also note with appreciation the indication of allowable subject matter being set forth in claim 2 and 9-15.

For the reasons set forth below, Applicants respectfully submit that one of the primary references utilized in the pending rejection does not constitute prior art to the application and therefore the pending rejection must be withdrawn.

**II. The Rejection Of The Claims Under 35 U.S.C. § 103**

Claims 1 and 3-8 were rejected under 35 U.S.C. § 103 as being unpatentable over USP No. 6,465,858 to Iida in view of USP No. 4,136,357 to Frederiksen. Applicants respectfully submit that Iida is not prior art to the instant application.

The instant application has an effective filing date of January 19, 2001 based on the priority claim under 35 U.S.C. § 119 to JP 2001-011165, which was filed on January 19, 2001. A certified translation of JP 2001-011165 is being submitted herewith in order to perfect the claim of priority.

The earliest effective filing date of Iida is September 27, 2001. Accordingly, as the effective filing date of Iida is later than the effective filing date of the instant application, Iida cannot be utilized as prior art to the instant application.

Thus, it is respectfully submitted that the pending rejections, which are all based on Iida, must be withdrawn.

**III. Request For Notice Of Allowance**

Having fully responded to all matters raised in the Office Action, Applicants submit that all claims are in condition for allowance, an indication for which is respectfully solicited. If there are any outstanding issues that might be resolved by an interview or an Examiner's amendment, the Examiner is requested to call Applicants' attorney at the telephone number shown below.

To the extent necessary, a petition for an extension of time under 37 C.F.R. 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account 500417 and please credit any excess fees to such deposit account.

Respectfully submitted,

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## Declaration for Translation of Priority Document

I, the undersigned Kazuhide Okada  
residing at Osaka, Japan

do solemnly and sincerely declare that I am well acquainted with the Japanese language and the English language and that the attached English translation of a certified copy of JP 2001-011165 filed on January 19, 2001 is a true, correct and faithful translation to the best of my knowledge and belief from the Japanese language into the English language.

Dated this 1st day of December, 2003

Kazuhide Okada

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[REGISTER NUMBER FOR PRE-PAYMENT] 007401

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[LIST OF FILED OBJECTS]

[NAME OF OBJECT] Specification 1

30 [NAME OF OBJECT] Drawings 1

[NAME OF OBJECT] Abstract 1

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[Title of Document] SPECIFICATION

[Title of the Invention] MOUNTING STRUCTURE OF SEMICONDUCTOR DEVICE AND MOUNTING METHOD OF SEMICONDUCTOR DEVICE

[Scope of Claims for Patent]

5 [Claim 1] A mounting structure of a semiconductor device characterized in that a terminal electrode provided at one face of a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode via a protruding electrode and a conductive adhesive agent with the one face opposed to a face of a circuit board having the input/output electrode formed thereon.

10 [Claim 2] A mounting structure of a semiconductor device characterized in that a terminal electrode provided at one face of a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode via solder with the one face opposed to a face of a circuit board having the input/output electrode formed thereon.

15 [Claim 3] A mounting structure of a semiconductor device according to Claim 2, wherein surroundings of a connection between the terminal electrode and the input/output electrode are encapsulated by an encapsulating resin.

20 [Claim 4] A mounting structure of a semiconductor device according to Claim 3, wherein an opposing portion between the compound semiconductor and the circuit board except the connection between the terminal electrode and the input/output electrode is encapsulated by the encapsulating resin.

25 [Claim 5] A mounting structure of a semiconductor device according to any of Claims 1 to 4, wherein a tip of a light-guiding optical fiber is fixed to the other face of the compound semiconductor substrate.

30 [Claim 6] A mounting structure of a semiconductor device according to Claim 5, wherein the light-guiding optical fiber is fixed to the other face by an adhesive resin.

[Claim 7] A mounting structure of a semiconductor device according to Claim 5 or 6, wherein the tip of the light-guiding optical fiber is arranged at a region of the other face opposite to a light-absorbing layer of the Pin-photodiode.

5 [Claim 8] A mounting structure of a semiconductor device according to any of Claims 5 to 7, wherein the other face is provided with a mounting hole formed therein toward the one face, so that the tip of the light-guiding optical fiber is inserted in the mounting hole to be fixed.

10 [Claim 9] A mounting structure of a semiconductor device according to Claim 8, wherein the mounting hole has such a depth that extends to a vicinity of the light-absorbing layer.

15 [Claim 10] A mounting structure of a semiconductor device according to Claim 5, further comprising an auxiliary mounting plate having a through-hole therein, so that the tip of the light-guiding optical fiber is fixed to the compound semiconductor substrate by fixing the auxiliary mounting plate to the other face with the tip of the light-guiding optical fiber as inserted and fixed in the through-hole of the auxiliary 20 mounting plate.

25 [Claim 11] A semiconductor device in a mounting structure of a semiconductor device according to Claim 3 or 4, characterized by further comprising an auxiliary mounting plate having a through-hole therein, so that the tip of the light-guiding optical fiber is fixed to the compound semiconductor substrate by fixing the auxiliary mounting plate to the other face by the encapsulating resin with the tip of the light-guiding optical fiber as inserted and fixed in the through-hole of the auxiliary mounting plate.

30 [Claim 12] A semiconductor device according to any of Claims 1 to 11, wherein the input/output electrode to be connected at least to either one of P-side and N-side electrodes of the Pin-photodiode is provided at such a site of the circuit

board that is opposite to a periphery of the compound semiconductor substrate.

[Claim 13] A mounting method of a semiconductor device wherein a terminal electrode provided at one face of a semiconductor device comprising a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode of a circuit board, comprising the steps of:

10 forming a protruding electrode to the terminal electrode to then supply a conductive adhesive agent on the protruding electrode;

15 installing the compound semiconductor substrate to the circuit board so that the terminal electrode and the input/output electrode are brought into contact with each other, and then, hardening the conductive adhesive agent to thereby mount the compound semiconductor substrate to the circuit board;

20 encapsulating a connection site between the compound semiconductor substrate and the circuit board by using an encapsulating resin; and

fixing a tip of a light-guiding optical fiber to the other face of the compound semiconductor substrate.

[Claim 14] A mounting method of a semiconductor device according to Claim 13, wherein the protruding electrode is 25 formed on the input/output electrode with both short-side faces of the compound semiconductor substrate as sandwiched by a jig.

[Claim 15] A mounting method of a semiconductor device wherein a terminal electrode provided at one face of a semiconductor device comprising a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode of a circuit board, comprising the steps of:

supplying solder to the input/output electrode;

installing the compound semiconductor substrate to the circuit board so that the terminal electrode and the input/output electrode are brought into contact with each other, and then, melting the solder to thereby mount the compound semiconductor substrate to the circuit board;

5       encapsulating a connection site between the compound semiconductor substrate and the circuit board by using an encapsulating resin; and

10      fixing a tip of a light-guiding optical fiber to the other face of the compound semiconductor substrate.

[Claim 16] A mounting method of a semiconductor device according to Claim 15, wherein heat and load are supplied to the solder to thereby produce a diffused compound between the solder and the terminal electrode.

15      [Claim 17] A mounting method of a semiconductor device according to Claim 15 or 16, wherein:

the light-guiding optical fiber is fixed to the compound semiconductor substrate with a photo-hardening resin and a photo-hardening resin is used as the encapsulating resin; and

20      the encapsulating resin and the resin for fixing the optical fiber are photo-hardened simultaneously.

[Detailed Description of the Invention]

[0001]

[Technical Field Pertinent to the Invention]

25      The present invention relates to a mounting structure of a semiconductor device in which a Pin-photodiode is mounted on a compound semiconductor substrate, and its mounting method.

[0002]

[Prior Art]

30      An expansion of a basic transmission capacity and a preparation of optical subscriber network systems are indispensable for realizing multimedia society in the future. An optical fiber was introduced for the first time to a

communication network of NTT in 1981. During ten years after that, it forms the main artery of relay network, thereby greatly supporting a current communication system.

[0003]

5 The optical fiber features "small loss", "small diameter", and "light weight" to thereby reduce the loss significantly as compared to a conventional metallic cable. This difference is remarkable in high speed transmission of signals, so that, to provide broadband services to the general homes in the near 10 future, the installment of the optical fiber is indispensable even in the subscriber line, and therefore, research and development have been proceeded about FTTH (fiber-to-the-home). In order to promote such research and development, measured 15 distance is required to be increased, and consequently, it is indispensable to develop a low-cost, high-band, and high-sensitivity light reception terminal (ONU).

[0004]

Because of the presence of the above-mentioned background, a super-lattice avalanche photo-diode (hereinafter 20 abbreviated as APD) and a Pin-photodiode (hereinafter abbreviated as PinPD) are drawing the attention as a high-performance photo-receptor element.

[0005]

[Problems to be solved by the Invention]

25 The APD has a basic operating principle of ionization-rate ratio control through band discontinuity of the super-lattice structure and an APD formed on a silicon (Si) substrate is commercially available already. The APD formed on a silicon (Si) substrate, however, has no sensitivity in the 30 1.55  $\mu\text{m}$  band and 1.3  $\mu\text{m}$  band for use in signal transfer by use of an optical fiber.

[0006]

As the APD that meets such demand, such a configuration

of the APD has been proposed that InGaAs(P)/InAlAs-based and In(Al)GaAs/InAlAs-based materials are lattice-matched on an InP substrate, those being proved to be of a high gain-bandwidth product and a high sensitivity in these signal transfer bands.

5 Further, in the above-mentioned APD structure, a planar-type element has been proposed that has a Ti ion-implanted guard-ring section. As disclosed in many literatures, however, when an electron-hole pair produced in the photo-absorbing layer is accelerated at the immediate strong electric field for 10 avalanche multiplication, the electron and hole are both multiplied, thus making it impossible to obtain a good high-frequency characteristic.

[0007]

On the other hand, such a structure is considered that 15 the photo-absorbing layer and the avalanche multiplication layer are separated from each other to thereby implant only electrons into the multiplication layer, thus multiplying the electrons selectively. In this structure, however, electrons 20 in the valence band of an electric-field relaxation layer will tunnel into the conduction band of the super-lattice multiplication layer owing to the strong electric field, thus contributing to the occurrence of a dark current wave.

[0008]

Further, as a premise, the APD is to be air-tight 25 encapsulated in a package, employing such a packaging scheme that, for example, a whole device is put in a case and then encapsulated air-tight in order to prevent as much as possible a water content from entering the package. This packaging, however, stands a bottleneck in manufacturing the APD at a low 30 cost.

[0009]

Thus, there are many problems of the APD to solve in terms of characteristic and reliability, thus preventing the APD from

being put to practical use to an acceptable level. Also, the structure of encapsulating the device as contained in a case for air-tightness is a hindrance in cost reduction. Also, the mesa-type structure suffers from especially a difficulty in  
5 control of an interfacial level of the mesa-etching portion, thus deteriorating the dark current. Therefore, a passivation film must be formed indispensably but prevents an optimal structure from being obtained.

[0010]

10 A PinPD, on the other hand, is generally formed on a compound semiconductor substrate specifically by a vapor-phase or liquid-phase growing method in manufacture, so that it is stable and has by far good reliabilities as compared to the APD. However, it does not have a super-lattice multiplication layer  
15 and so has no carrier multiplication action, thus suffering from a problem of a small margin in specifications for obtaining higher performance.

[0011]

20 The present invention aims to provide a semiconductor device further improved in characteristic and reliability by using a PinPD stable in characteristic and reliability although its potential characteristics are inferior to an APD because it has no carrier multiplication action.

[0012]

25 [Means for Solving the Problems]

In order to solve the above-mentioned problems, a terminal electrode provided at one face of a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode via a protruding electrode and a  
30 conductive adhesive agent with the one face opposed to a face of a circuit board having the input/output electrode formed thereon.

[0013]

[Best Mode for Carrying out the Invention]

The invention described in claim 1 of the present invention is characterized in that a terminal electrode provided at one face of a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode via a protruding electrode and a conductive adhesive agent with the one face opposed to a face of a circuit board having the input/output electrode formed thereon, whereby the following operation is obtained. Specifically, the compound semiconductor substrate can be connected to the circuit board with a short wiring distance, thus improving the high-frequency characteristics.

[0014]

The invention described in claim 2 of the present invention is characterized in that a terminal electrode provided at one face of a compound semiconductor substrate having a Pin-photodiode is connected to an input/output electrode via solder with the one face opposed to a face of a circuit board having the input/output electrode formed thereon, whereby the following operation is obtained. Specifically, the compound semiconductor substrate can be connected to the circuit board with a short wiring distance, thus improving the high-frequency characteristics.

[0015]

The invention described in claim 3 of the present invention is characterized in that, in the semiconductor device according to claim 2, surroundings of a connection between the terminal electrode and the input/output electrode are encapsulated by an encapsulating resin, whereby the following operation is obtained. Specifically, a simple structure of resin encapsulation is enough to encapsulate the mounting structure, thus reducing the costs by that much.

[0016]

5 To secure encapsulation, preferably the opposing portion between the compound semiconductor and the circuit board except the connection between the terminal electrode and the input/output electrode is encapsulated by the encapsulating resin as the encapsulation structure as described in claim 4.

10 The invention described in claim 5 of the present invention is characterized in that, in the mounting structure of a semiconductor device according to any one of claims 1 to 4, a tip of a light-guiding optical fiber is fixed to the other face of the compound semiconductor substrate, whereby the following operation is obtained. Specifically, applying a flip-chip-wise mounting structure disclosed in the invention in the above-mentioned each claim enables to fixedly install the light-guiding optical fiber to the other face of the 15 compound semiconductor substrate, whereby the installing structure of the light-guiding optical fiber is simplified, thereby reducing cost and accomplishing miniaturization.

[0017]

20 It is to be noted that the light-guide optical fiber is preferably fixed to the other face by the adhesive resin as described in claim 6, that enables to further simplify the installing structure of the light-guiding optical fiber, thereby leading to the reduction in cost.

25 It is to be noted that the tip of the optical fiber is preferably arranged at a region of the other face opposite to a light-absorbing layer of the Pin-photodiode as described in claim 7, thereby improving the photo-absorbing efficiency.

[0019]

30 Further, the other face is preferably provided with a mounting hole formed therein toward the one face, so that the tip of the light-guiding optical fiber is inserted in the mounting hole to be fixed, as described in claim 8, thereby facilitating and ensuring the fixation of the light-guiding

optical fiber.

[0020]

Moreover, the mounting hole has preferably such a depth that extends to a vicinity of the light-absorbing layer, as 5 described in claim 9, thereby further improving the photo-absorbing efficiency.

[0021]

Additionally, an auxiliary mounting plate having a through-hole therein is preferably further provided, so that 10 the tip of the light-guiding optical fiber is fixed to the compound semiconductor substrate by fixing the auxiliary mounting plate to the other face with the tip of the light-guiding optical fiber as inserted and fixed in the through-hole of the auxiliary mounting plate, as described in claim 10, 15 thereby facilitating and ensuring the fixation of the light-guiding optical fiber.

[0022]

Moreover, an auxiliary mounting plate having a through-hole therein is preferably further provided, so that 20 the tip of the light-guiding optical fiber is fixed to the compound semiconductor substrate by fixing the auxiliary mounting plate to the other face by the encapsulating resin with the tip of the light-guiding optical fiber as inserted and fixed in the through-hole of the auxiliary mounting plate, as 25 described in claim 11, thereby facilitating and ensuring the fixation of the light-guiding optical fiber.

[0023]

Further, in the semiconductor device described in claims 1 to 11, the input/output electrode to be connected at least 30 to either one of P-side and N-side electrodes of the Pin-photodiode is preferably provided at such a site of the circuit board that is opposite to a periphery of the compound semiconductor substrate, as described in claim 12, whereby a

floating capacitance between the input/output electrode of the circuit board and the compound semiconductor substrate is difficult to occur.

[0024]

5 It is to be noted that, as described in claim 13, the mounting structure of the semiconductor device of the present invention can be manufactured by a mounting method including the steps of forming a protruding electrode to the terminal electrode to then supply a conductive adhesive agent on the 10 protruding electrode, installing the compound semiconductor substrate to the circuit board so that the terminal electrode and the input/output electrode are brought into contact with each other, and then, hardening the conductive adhesive agent to thereby mount the compound semiconductor substrate to the 15 circuit board, encapsulating a connection site between the compound semiconductor substrate and the circuit board by using an encapsulating resin and fixing a tip of a light-guiding optical fiber to the other face of the compound semiconductor substrate.

20 [0025]

Further, as described in claim 15, the mounting structure of the semiconductor device of the present invention can be manufactured by a mounting method including the steps of supplying solder to the input/output electrode installing the 25 compound semiconductor substrate to the circuit board so that the terminal electrode and the input/output electrode are brought into contact with each other, and then, melting the solder to thereby mount the compound semiconductor substrate to the circuit board encapsulating a connection site between the compound semiconductor substrate and the circuit board by 30 using an encapsulating resin and fixing a tip of a light-guiding optical fiber to the other face of the compound semiconductor substrate.

[0026]

It is to be noted that, in the mounting method according to claim 13, the protruding electrode is preferably formed on the input/output electrode with both short-side faces of the compound semiconductor substrate as sandwiched by a jig, as described in claim 14, thereby being capable of avoiding damaging of the compound semiconductor substrate.

[0027]

It is to be noted that, in the mounting method according to claim 15, heat and load are preferably supplied to the solder to thereby produce a diffused compound between the solder and the terminal electrode, as described in claim 16, thereby enabling securely interconnecting the input/output electrode and the terminal electrode without performing an extra step of applying flux to the solder.

[0028]

It is to be noted that, in the mounting method of the present invention, the light-guiding optical fiber is preferably fixed to the compound semiconductor substrate with a photo-hardening resin and a photo-hardening resin is used as the encapsulating resin and the encapsulating resin and the resin for fixing the optical fiber are photo-hardened simultaneously, as described in claim 17, thereby simplifying the step of hardening these resins.

[0029]

Embodiment 1

Fig. 1 outlines a mounting structure of a semiconductor device according to the embodiment 1 of the present invention. This semiconductor device A is made of an InP substrate or the like and has a compound semiconductor substrate B having a PinPd (Pin-photodiode) 1 that is a photoreceptor element provided therein. A terminal electrode 2 is provided at one face of the compound semiconductor substrate B. A backward high voltage

is applied to the pn junction of the PinPD 1 to thereby accelerate an electron-hole pair generated in a photo-absorbing layer of the PinPD 1.

[0030]

5       A protruding electrode 3 is formed on the terminal electrode 2. The protruding electrode 3 is electrically connected to and fixed onto an input/output electrode 6 of a circuit board 7 via a conductive adhesive agent 4, and its connection (opposing section between the circuit board 7 and 10 the compound semiconductor substrate B) is encapsulated and reinforced by an encapsulating resin 5. This causes the semiconductor device A to be mounted on the circuit board 7. Note here that the encapsulating resin 5 only needs to reinforce at least the surroundings of the connection of the input/output 15 electrode 6. Also, the protruding electrode 3 may be formed by wire bonding, plating, or any other method.

[0031]

Thus, the compound semiconductor substrate B having the PinPD 1 mounted thereon is mounted flip-chip-wise to the circuit 20 board 7. This makes it possible to connect the compound semiconductor substrate B to the circuit board 7 with a short wiring distance, whereby a mounting structure excellent in high-frequency characteristic can be realized and a light-guiding optical fiber 8 can be adhered to the other face (the 25 face positioned to the side opposite to the face on which the terminal electrode is formed) of the compound semiconductor substrate B.

[0032]

In the present embodiment, the tip of the light-guiding 30 optical fiber 8 is adhered to the semiconductor device A with an adhesive agent 9 made of a thermo-hardening resin or the like. It is to be noted that the tip of the light-guiding optical fiber 8 is arranged at the position opposing to the photo-absorbing

layer of the PinPD 1 in order to efficiently introduce light to the PinPD 1.

[0033]

5 The following will describe a result of measuring the reliability of the mounting structure of the semiconductor device of this embodiment with reference to Fig. 2. Here, the following was used as one example of this embodiment. That is, such a structure was used as one example of this embodiment that the protruding electrode 3 was formed by wire bonding on the 10 terminal electrode 2 of the semiconductor device A that incorporates the PinPD 1 on the compound semiconductor substrate B made of a 0.1  $\mu\text{m}$ -thick InP substrate for making it possible to adhere the optical fiber from the other face (the back face of the semiconductor device A) of the compound 15 semiconductor substrate, and then, the semiconductor device A is mounted to the terminal electrode 6 of the circuit board 7 via this protruding electrode 3 and the conductive adhesive agent 4, whereupon the reliability of this example was measured.

[0034]

20 FIG. 2(a) indicates a result of measuring an increase in the dark current when a solder heat test (270°C, 5 cycles) was conducted under the conditions of a reverse-bias application voltage of 0-15V. FIG. 2(b) indicates a result of measuring an increase of the dark current when a high-temperature, 25 high-humidity test was conducted under the conditions of a temperature of 85°C, a humidity of 85 %RH, and a time of 1712 hours. FIGS. 2(C-1) and (2C-2) indicate a result of measuring an increase in the dark current when a temperature cycle test (-40°C to 125°C) was conducted 400 cycles.

30 [0035]

As can be seen from each data of Fig. 2, the mounting structure of the semiconductor device of this embodiment exhibited little deterioration in the dark current, proving an

excellent reliability of the mounting structure of the embodiment. It is considered because the semiconductor device A is mounted via the conductive adhesive agent 4 to the circuit board 7, so that this mounting requires only a relatively small 5 application pressure (approximately 40 g/terminal electrode for the formation of the protruding electrode, approximately 5 g/terminal electrode for the mounting), thus avoiding damaging the semiconductor device A.

[0036]

10 Preferably, the photo-absorbing layer of the PinPD1 is made of any combination of at least II-group elements of Zn, Cd, and Hg, III-group elements of B, Al, Ga, In, and TI, V-group elements of N, P, As, Sb, and Bi, and VI-group elements of O, S, Se, Te, and Po. Also, preferably a conductive filler 15 of the conductive adhesive agent 4 contains at least one of Ag, Pd, Ni, Au, Cu, C, and Pt. Preferably the encapsulating resin 5 contains an epoxy-based resin as its main component and also inorganic particulate. The inorganic particulate includes,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{SiN}$ ,  $\text{AlN}$  etc.

20 [0037]

The following will describe a method for manufacturing the mounting structure of this embodiment with reference to FIGS. 3.

[0038]

25 First, as shown in FIG. 3(a), the protruding electrode 3 is formed on the terminal electrode 2 of the semiconductor device A. Next, as shown in FIG. 3(b), the conductive adhesive agent 4 is formed to a constant thickness in position in a container C and then a tip of the protruding electrode 3 on the 30 terminal electrode 2 is dipped in this conductive adhesive agent 4, thus transferring the conductive adhesive agent 4 to the protruding electrode 3.

[0039]

Next, as shown in FIG. 3(c), the terminal electrode 2 is connected and fixed to the input/output electrode 6 via the conductive adhesive agent 4, thus mounting the semiconductor device A to the circuit board 7. Then, as shown in FIG. 3(d), 5 the surroundings of a connection at the opposing portion between the circuit board 7 and the compound semiconductor substrate B are encapsulated and reinforced with the encapsulating resin 5. In this step, the encapsulating resin 5 needs only to reinforce the surroundings of the connection.

10 [0040]

Finally, as shown in Fig. 3(e), the light-guiding optical fiber 8 is positioned on the photo-absorbing layer of the semiconductor device A (specifically the PinPD 1) in such a manner as to maximize the photo-absorbing efficiency for the 15 PinPD 1 and then is adhered and fixed to the back face (the face positioned at the side opposite to the face on which the terminal electrode is formed and the other face of the semiconductor substrate B) of the semiconductor device A using the adhesive agent 9 such as a thermo-hardening resin or the like.

20 [0041]

Embodiment 2

Although the embodiment 1 described above has used the conductive adhesive agent 4 to mount the semiconductor device A to the circuit board 7, the present invention is not limited 25 to use of such an adhesive agent. As shown in Fig. 4, this embodiment is characterized in that solder 10 is used in place of the conductive adhesive agent 4 to thereby connect and fix the terminal electrode 2 of the semiconductor device A to the input/output electrode 6 of the circuit board 7. Moreover, in 30 a structure of this embodiment, the device is mounted using only the solder 10 without providing the protrusion electrode 3. The other structure details are basically the same as those of the first embodiment and so their explanation is omitted. Also,

the encapsulating resin 5 need not be used for reinforcement if the reliability can be preserved for thermal distortion to which are related the size of the semiconductor device A and the material of the compound semiconductor substrate B. Also, 5 preferably the solder 10 contains at least one of Sn, Ag, Pb, Bi, Cu, Zn, and Sb.

[0042]

10 The following will describe a first method for manufacturing the mounting structure of the semiconductor device of this embodiment with reference to FIGS. 5.

[0043]

15 First, as shown in FIG. 5(a), the solder 10 is supplied by printing to the input/output electrode 6 of the circuit board 7. Specifically, the solder 10 is supplied through a screen mask 11 using a squeegee 12 to the surface of the input/output electrode 6.

[0044]

20 Next, as shown in FIG. 5(b), the terminal electrode 2 is aligned with the input/output electrode 6 to then mount the semiconductor device A on the circuit board 7 and, in this state, conduct reflow processing, etc. to thereby melt the solder 10, thus connecting the terminal electrode 2 to the input/output electrode 6.

[0045]

25 Next, as shown in FIG. 5(c), the encapsulating resin 5 is used to encapsulate the connection for reinforcement. In this step, the encapsulating resin 5 needs only to reinforce at least the surroundings of the connection. Also, the encapsulating resin 5 need not be used for reinforcement if the 30 reliability can be preserved for the thermal distortion to which are related the size of the semiconductor device A, the materials of the compound semiconductor substrate B and the circuit board 7, etc.

[0046]

Finally, as shown in FIG. 5(d), the light-guiding optical fiber 8 is positioned on the back face (the face at the side opposite to the face on which the terminal electrode is formed 5 and the other face of the compound semiconductor substrate B) of the semiconductor device A so that the photo-absorbing layer of the semiconductor device A may have the maximum photo-absorbing efficiency and then adhered to the semiconductor device A using the adhesive agent 9.

10 [0047]

The following will describe a second method for manufacturing the mounting structure of the semiconductor device of this embodiment with reference to FIGS. 6.

[0048]

15 First, as shown in Fig. 6(a), the solder 10 is formed on the input/output electrode 6 of the circuit board 7 by plating. Then, as shown in Fig. 6(b), the terminal electrode 2 of the semiconductor device A is fixedly connected to the input/output electrode 6 of the circuit board 7 by using both heat and load. 20 In this step, the solder 10 has its surface oxide film broken by the heat and load to thereby produce a metallic compound between itself and the input/output electrode 2, thereby serving a firm connection both mechanically and electrically.

[0049]

25 Next, as shown in FIG. 6(c), the connection between the semiconductor device A and the circuit board 7 is encapsulated and reinforced by the encapsulating resin 5. In this step, the encapsulating resin 5 needs only to reinforce the surroundings of the connection. Also, the encapsulating resin 5 need not 30 be used for reinforcement if the reliability can be preserved for thermal distortion to which are related the size of the semiconductor device A and the material of the compound semiconductor substrate B and the circuit board 7.

[0050]

Finally, as shown in Fig. 6(d), the light-guiding optical fiber 8 is positioned on the back face (the face of the compound semiconductor substrate B positioned at the side opposite to the face on which the terminal electrode is formed and the other face thereof) of the semiconductor device A in such a manner as to maximize the photo-absorbing efficiency of the photo-absorbing layer of the semiconductor device A and then is adhered to the semiconductor device A using the adhesive agent 9.

[0051]

Although this embodiment described above has supplied the encapsulating resin to cover and thereby reinforce the connection between the semiconductor device A and the circuit board 7, the encapsulating resin 5 may be supplied only to the periphery of the compound semiconductor substrate B as shown in FIG. 7.

[0052]

The following will describe the method for manufacturing a mounting structure in this case with reference to Fig. 8. First, the semiconductor device A is mounted to the circuit board 7 according to the method shown in Figs. 8(a) and 8(b) same as that described with reference to Figs. 5(a) and 5(b). Then, the encapsulating resin 5 made of a photo-hardening resin (e.g., ultraviolet-hardening resin) is placed as unhardened at the periphery of the semiconductor device A at the connection between the semiconductor device A and the circuit board 7. In this state, the light-guiding optical fiber 8 is further abutted to and placed on the back face (the other face of the compound semiconductor substrate B) of the semiconductor device A via the adhesive agent 9 made of a similar photo-hardening resin (as unhardened).

[0053]

Then, an ultraviolet ray is applied to the encapsulating resin 5 and the adhesive agent 9 simultaneously to thereby harden only the surfaces of the encapsulating resin 5 and the adhesive agent 9. By doing so, the light-guiding optical fiber 8 can be properly positioned while simultaneously preventing the encapsulating resin 5 from flowing into the connection. Then, the encapsulating resin 5 and the adhesive agent 9 are heated to be hardened permanently.

[0054]

10 Third Embodiment

Although a mounting structure of the second embodiment described above has used only the solder 10 to mount the semiconductor device A to the circuit board 7, the present invention is not limited to use of such an adhesive medium. As 15 by this embodiment, as shown in FIG. 9, the protruding electrode 3 is formed on the terminal electrode 2 to then connect and fix the terminal electrode 2 of the semiconductor device A to the input/output electrode 6 of the circuit board 7 by interposing the solder 10 between the protruding electrode 3 and the 20 input/output electrode 6. The solder 10 is specifically formed as pasted on the input/output electrode 6 of the circuit board 7 and then melted by reflow processing to thereby connect and fix the connection electrode 6 and the terminal electrode 2 to each other. Alternatively, the solder 10 may be formed to the 25 connection electrode 6 without supplying flux to then has oxide film of the solder 10 broken using heat and load simultaneously in order to produce a metallic compound between the solder 10 and the protruding electrode 3, thus connecting and fixing the input/output electrode 6 and the terminal electrode 2 to each 30 other.

[0055]

The other structure details are basically the same as those of the first embodiment and their explanation is omitted.

Also, the encapsulating resin 5 need not be used for reinforcement if the reliability can be preserved for thermal distortion to which are related the size of the semiconductor device A and the material of the compound semiconductor substrate B. Also, preferably the solder 10 contains at least one of Sn, Ag, Pb, Bi, Cu, Zn, and Sb.

[0056]

The above-mentioned first through third embodiments of the present invention have their respective features in the structure for interconnecting the semiconductor device A and the circuit board 7. The following will describe fourth through sixth embodiments of the present invention which have their respective features in the light-guiding optical fiber 8 installing structure and seventh and eighth embodiments of the present invention which further have the other features.

[0057]

Note here that the embodiments to be described as follows have no features in particular in the structure for interconnecting the semiconductor device A and the circuit board 7. Therefore, a connection portion between the semiconductor device A and the circuit board 7 is simply called a connection 14. The connection 14 here, of course, contains a structure for connection by use of the conductive adhesive agent 4 or the solder 10.

[0058]

Embodiment 4

Fig. 10 outlines a mounting structure of the semiconductor device A according to the embodiment 4 of the present invention. In this mounting structure, the semiconductor device A is mounted via the connection 14 to the circuit board 7, and a mounting hole 13 is formed on the back face (the face positioned to the side opposite to the face on which the terminal electrode is formed and the other face of

the compound semiconductor substrate B) of the compound semiconductor substrate B. The mounting hole 13 is formed as bottomed along the thickness direction of the substrate B toward the face on which the terminal electrode is formed (the one face 5 of the compound semiconductor substrate B) and to such a size that the light-guiding optical fiber 8 can be inserted therein.

[0059]

The tip of the light-guiding optical fiber 8 is fixed, as inserted in the mounting hole 13, to the compound 10 semiconductor substrate B using the adhesive agent 9. This configuration permits the tip of the light-guiding optical fiber 8 to come close to the photo-absorbing layer of the PinPD1 as much as possible, thus preserving a sufficient level of light receiving sensitivity.

15 [0060]

Embodiment 5

Fig. 11 outlines a mounting structure of the semiconductor device A according to the embodiment 5 of the present invention. In this mounting structure, the 20 semiconductor device A is mounted via the connection 14 to the circuit board 7, and an auxiliary mounting plate 16 is fixed face-to-face on the back face (the face positioned to the side opposite to the face on which the terminal electrode is formed and the other face of the compound semiconductor substrate B) 25 of the compound semiconductor substrate B. The auxiliary mounting plate 16 has a mounting hole 17 formed along its thickness direction. The mounting hole 17 is specifically formed through the auxiliary mounting plate 16 and to such a size that the light-guiding optical fiber 8 can be inserted 30 therein.

[0061]

The tip of the light-guiding optical fiber 8 is fixed, as inserted in the mounting hole 17, to the auxiliary mounting

plate 16 using the adhesive agent 9, and further fixed to the compound semiconductor substrate B via the auxiliary mounting plate 16. Mounting the auxiliary mounting plate 16 enables to keep the mechanical strength of the compound semiconductor substrate B by the auxiliary mounting plate 16, thus making the thickness of the compound semiconductor substrate B thin that much. By this embodiment, therefore, the thickness of the compound semiconductor substrate B can be thus decreased to thereby permit the tip of the light-guiding optical fiber 8 to come close to the photo-absorbing layer of the PinPD 1 by that much, thus preserving a sufficient level of the light receiving sensitivity.

[0062]

Alternatively, as shown in FIG. 12, the size of the mounting hole 17 may mostly match the profile of the light-guiding optical fiber 8 to thereby fix the light-guiding optical fiber 8 by pressure into the mounting hole 17.

[0063]

Also, the auxiliary mounting plate 16 of this embodiment can be installed and fixed using the encapsulating resin 5 to thereby eliminate the independent step of installing the auxiliary mounting plate 16 in order to simplify the manufacturing process, thus reducing the costs.

[0064]

25 Sixth Embodiment

FIG. 13 outlines a mounting structure of the semiconductor device A according to the sixth embodiment of the present invention. In this mounting structure, the semiconductor device A is mounted via the connection 14 to the circuit board 7, in which in turn is formed a mounting hole 18. The mounting hole 18 is formed through the circuit board 7 along the thickness direction of the circuit board 7 and to such a size that the optical fiber 8 can be inserted therein.

[0065]

The tip of the light-guiding optical fiber 8 is fixed, as inserted in the mounting hole 13 to the compound semiconductor substrate B on its one face (on which the terminal electrode is formed) using the encapsulating resin 5. This configuration permits the tip of the light-guiding optical fiber 8 to come close to the photo-absorbing layer of the PinPD 1 as much as possible, thus preserving a sufficient level of light receiving sensitivity.

10 [0066]

Alternatively, as shown in FIG. 14, on either one of the right and back faces of the circuit board 7 (on the face on which the input/output electrode is formed in FIG. 14) a positioning block 19 may be disposed so as to surround the mounting hole 18. This configuration facilitates the positioning of the optical fiber 8. The positioning block 19 may be a resist, a chip element, or any other as far as it does not interfere with the wiring circuit on the circuit board 7. In the structure shown in FIG. 14, the light-guiding optical fiber 8 is fixed with the adhesive agent 9 and the encapsulating resin 5 is provided only at the periphery of the compound semiconductor substrate B. This is, however, just one example and, of course, the surroundings of the connection 14 may be encapsulated completely with the encapsulating resin 5 or the optical fiber 8 may be fixed by pressure into the mounting hole 18.

25 [0067]

Seventh Embodiment

FIGS. 15 outline a mounting structure of the semiconductor device A according to the seventh embodiment of the present invention. FIG. 15(a) shows a wiring electrode 20 of the semiconductor device A as viewed from the above and FIG. 15(b) is a cross-sectional view for showing the semiconductor device A as mounted to the circuit board 7.

[0068]

The semiconductor device A may sometimes have such a configuration that the underlying compound semiconductor substrate B as a whole acts as the N-side electrode, so that 5 if the connection 14 extended from the P-side electrode is present at the center of the semiconductor device A, a floating capacitance may possibly occur there between the connection electrode 6 of the circuit board 7 pulled around thereto and the compound semiconductor substrate B underlying the 10 light-receiving photo-semiconductor device A which acts as the N-side electrode. Such a floating capacitance may deteriorate the high-frequency characteristic remarkably. To solve this problem, in this embodiment, as shown in FIG. 15(b), the input/output electrode 6 of the circuit board 7 connected to 15 the connection 14 which acts as the P-side electrode is disposed outside the semiconductor device A as much as possible in design. This configuration makes it possible to prevent characteristics from being deteriorated due to the occurrence of the floating capacitance, thus realizing the mounting structure excellent 20 in high-frequency characteristic.

[0069]

Note here that the compound semiconductor substrate B has a cleavage face and so is brittle and fragile as compared to a silicon (Si) substrate. Therefore, when the protruding electrode 3 is provided in the embodiments of the present 25 invention, an attempt to form the protruding electrode 3 using the wire bonding method may sometimes cause damage on the compound semiconductor substrate B. In such a case, as shown in FIG. 16, the side of the shorter-side Ba of the compound 30 semiconductor substrate B can be sandwiched by a jig 21 to then form the protruding electrode 3 by wire bonding to thereby remarkably mitigate damage (cracks etc.) on the compound semiconductor substrate B, thus further preventing the

deterioration in the high-frequency characteristic and the current characteristic (dark current, photo-electric current, etc.) of the light-receiving photo-semiconductor device. Note here that a reference numeral 19 in FIG. 16 indicates a bonding 5 stage.

[0070]

[Effect of the Invention]

As may be clear from the explanation above, the invention 10 enables an air-tight encapsulation by use of an encapsulating resin, thus eliminating the necessity of otherwise encapsulating in an air-tight manner by use of a package structure. This technology is not established yet conventionally. This new technology enables reducing the 15 costs. Also, a mounting structure can be made that is excellent in the high-frequency characteristic, the current characteristic (dark current, photo-electric current, etc.) and reliability. Also, the semiconductor device of the invention can be manufactured in such stable processes as the vapor-phase growing method or liquid-phase growing method to 20 thereby be free of characteristic deterioration due to humidity in contrast to a prior art one, thus providing a further stabled mounting structure.

[Brief Description of the Drawings]

[Fig. 1] A sectional view showing a mounting structure 25 of a semiconductor device according to an embodiment 1 of the present invention.

[Fig. 2] A view showing characteristics data of the mounting structure of the semiconductor device of the embodiment 1.

30 [Fig. 3] Schematic views showing a manufacturing method of the mounting structure of the embodiment 1.

[Fig. 4] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 2.

[Fig. 5] Schematic views showing a first manufacturing method of the mounting structure of the embodiment 2.

[Fig. 6] Schematic views showing a second manufacturing method of the mounting structure of the embodiment 2.

5 [Fig. 7] A sectional view showing a modified example of the embodiment 2 of the present invention.

[Fig. 8] Schematic views showing a manufacturing method of the modified example of the embodiment 2.

10 [Fig. 9] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 3 of the present invention.

[Fig. 10] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 4 of the present invention.

15 [Fig. 11] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 5 of the present invention.

[Fig. 12] A sectional view showing a modified example of the embodiment 5.

20 [Fig. 13] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 6 of the present invention.

[Fig. 14] A sectional view showing a modified example of the embodiment 6.

25 [Fig. 15] A sectional view showing a mounting structure of a semiconductor device according to an embodiment 7 of the present invention.

30 [Fig. 16] A schematic view showing a structure of a modified example according to all embodiments of the present invention.

[Description of Reference Numerals]

A Semiconductor device

B Compound semiconductor substrate

- 1 PinPD
- 2 Terminal electrode
- 3 Protruding electrode
- 4 Conductive adhesive agent
- 5 Encapsulating resin
- 6 Input/output electrode
- 7 Circuit board
- 8 Light-guiding optical fiber
- 9 Adhesive agent
- 10 Solder
- 13 Mounting hole
- 14 Connection
- 16 Auxiliary mounting plate
- 19 Positioning block

[Title of Document]      ABSTRACT

[Abstract]

[Object]

5      The provision of a mounting structure of a semiconductor device having a Pin-photodiode that ensures characteristics and reliability without performing an air-tight encapsulation.

[Solving Means]

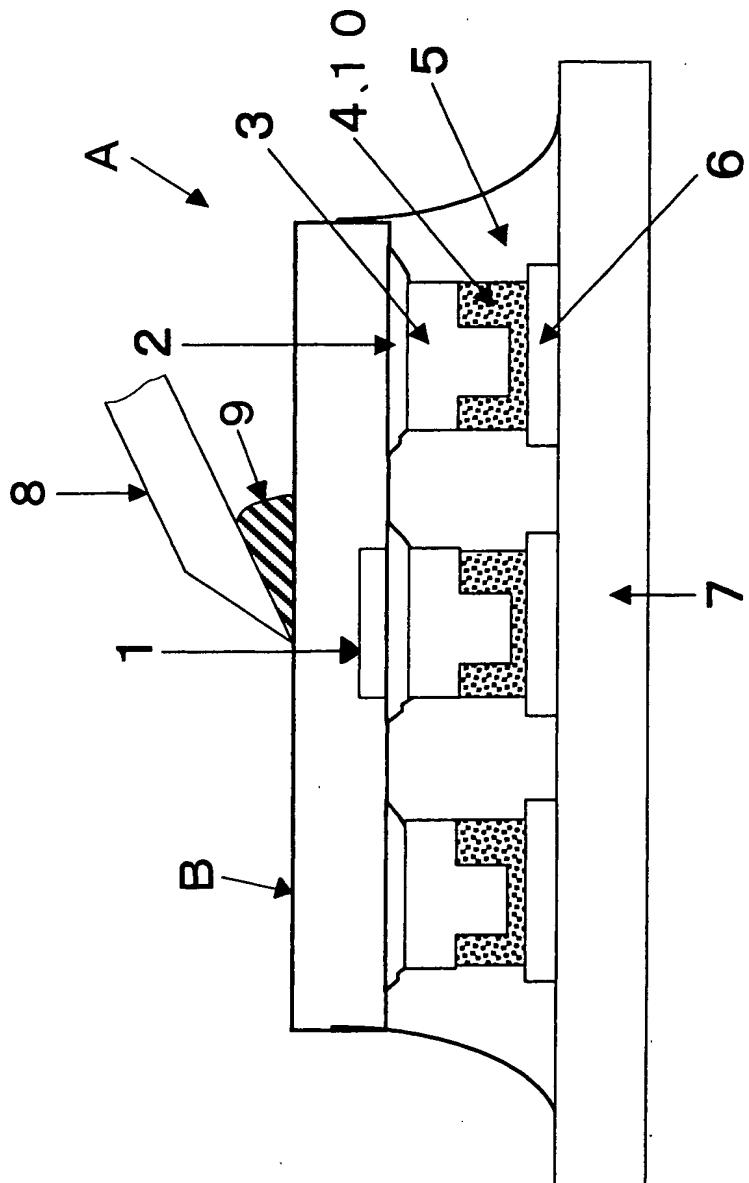
10     A terminal electrode 2 provided at one face of a compound semiconductor substrate B having a Pin-photodiode 1 is connected to an input/output electrode 6 of a circuit board 7 via a protruding electrode 3 and a conductive adhesive agent 4 or solder 10, and the surroundings of a connection between the terminal electrode 2 and the input/output electrode 6 are encapsulated by an encapsulating resin 5. This configuration 15     makes it possible to connect the compound semiconductor substrate B to the circuit board 7 with a short wiring distance and to encapsulate the mounting structure with a simple structure.

[Selected Drawing]      Fig. 1

【Name of the Document】

## Drawing

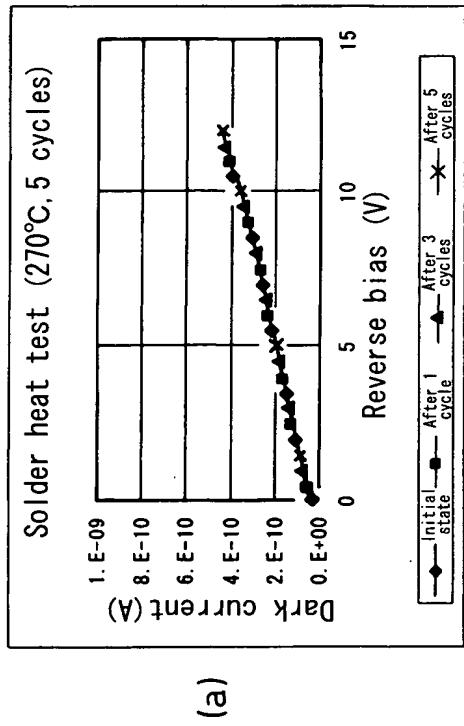
[FIG. 1]



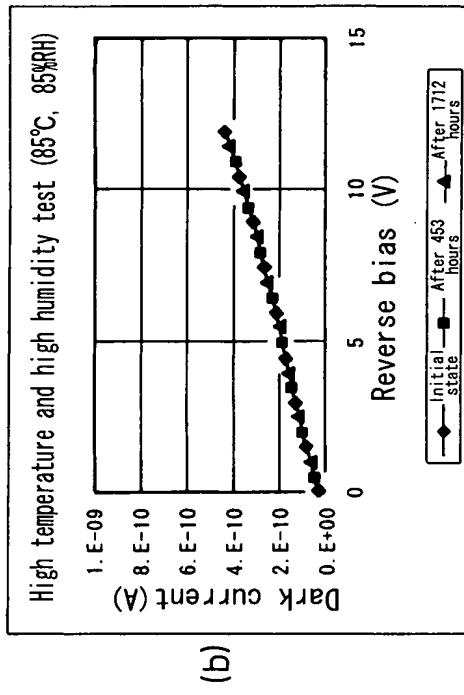
[FIG. 2]



Solder heat test (270°C, 5 cycles)

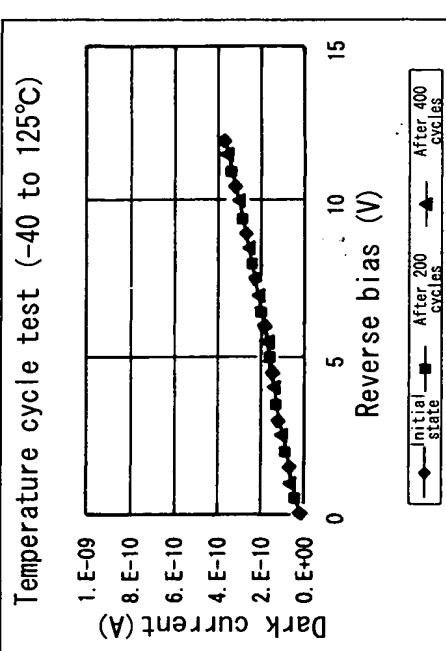


High temperature and high humidity test (85°C, 85%RH)



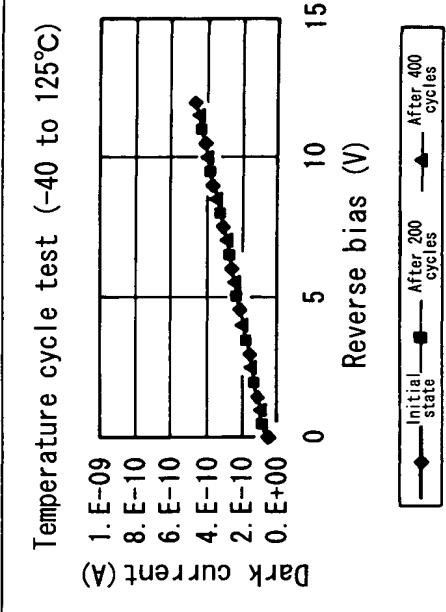
Temperature cycle test (-40 to 125°C)

Sample 1

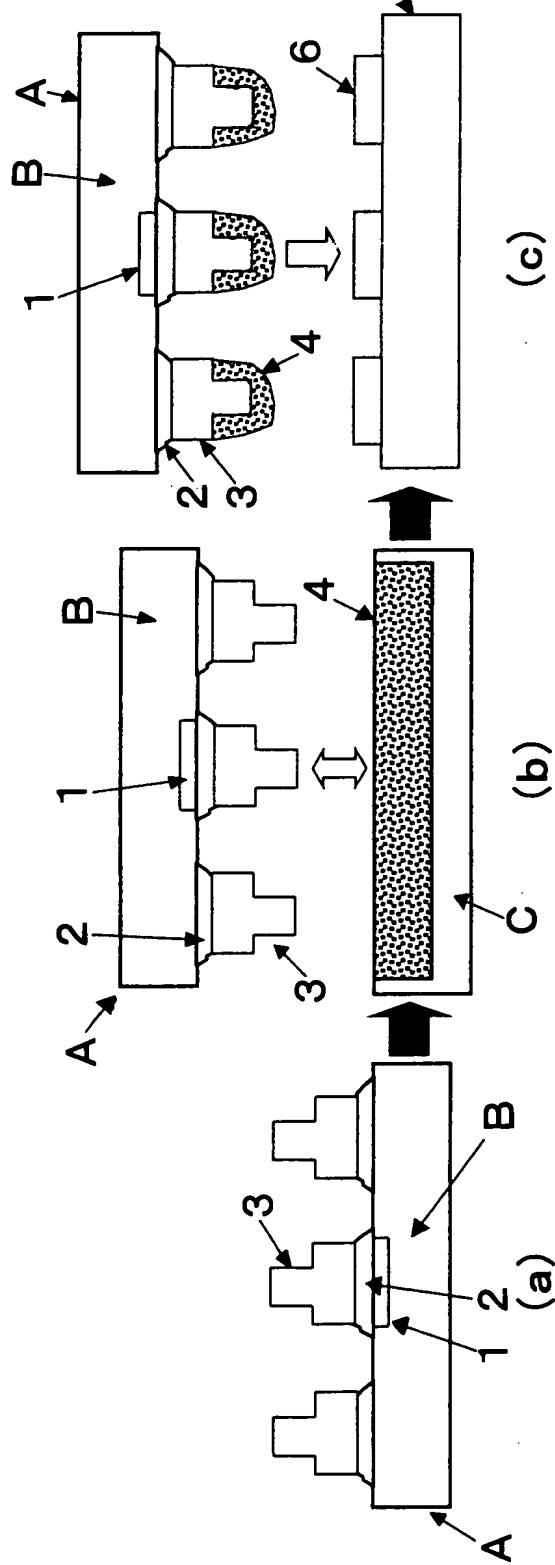


Temperature cycle test (-40 to 125°C)

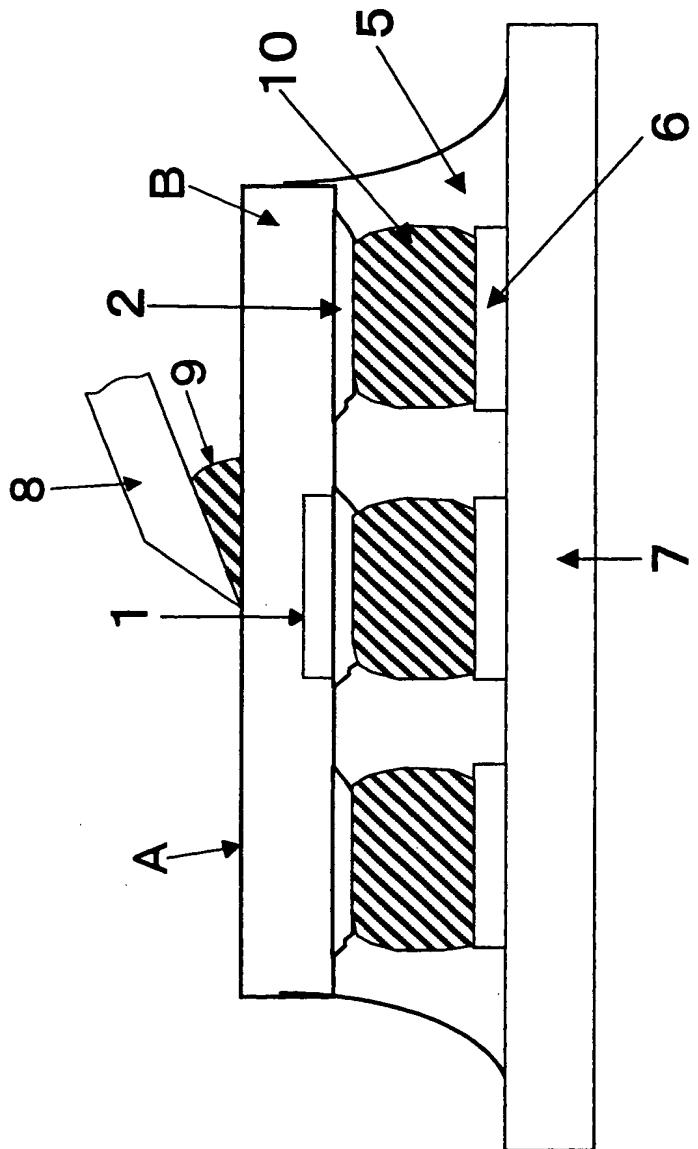
Sample 2



【FIG. 3】

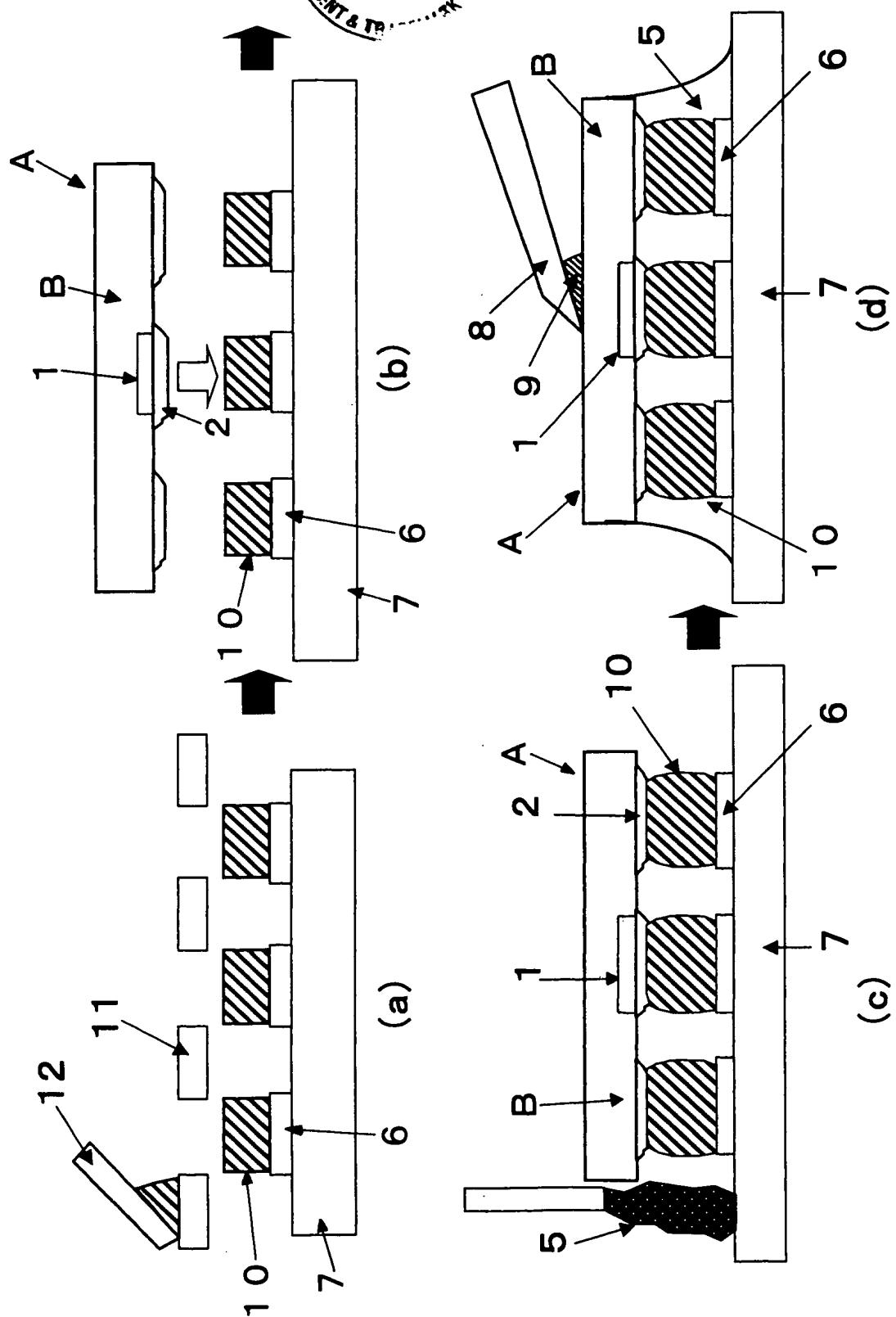


[FIG. 4]

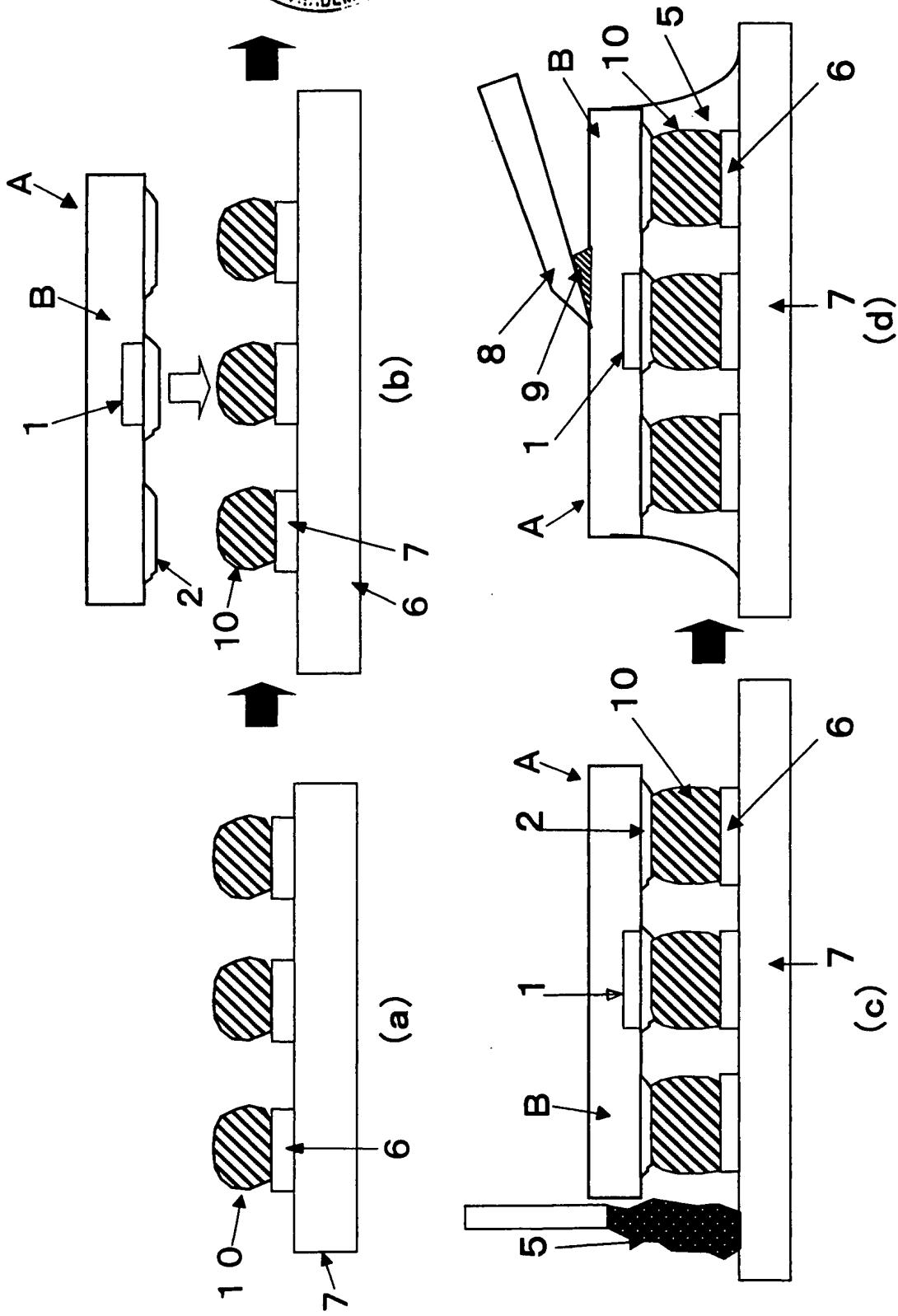


[FIG. 5]

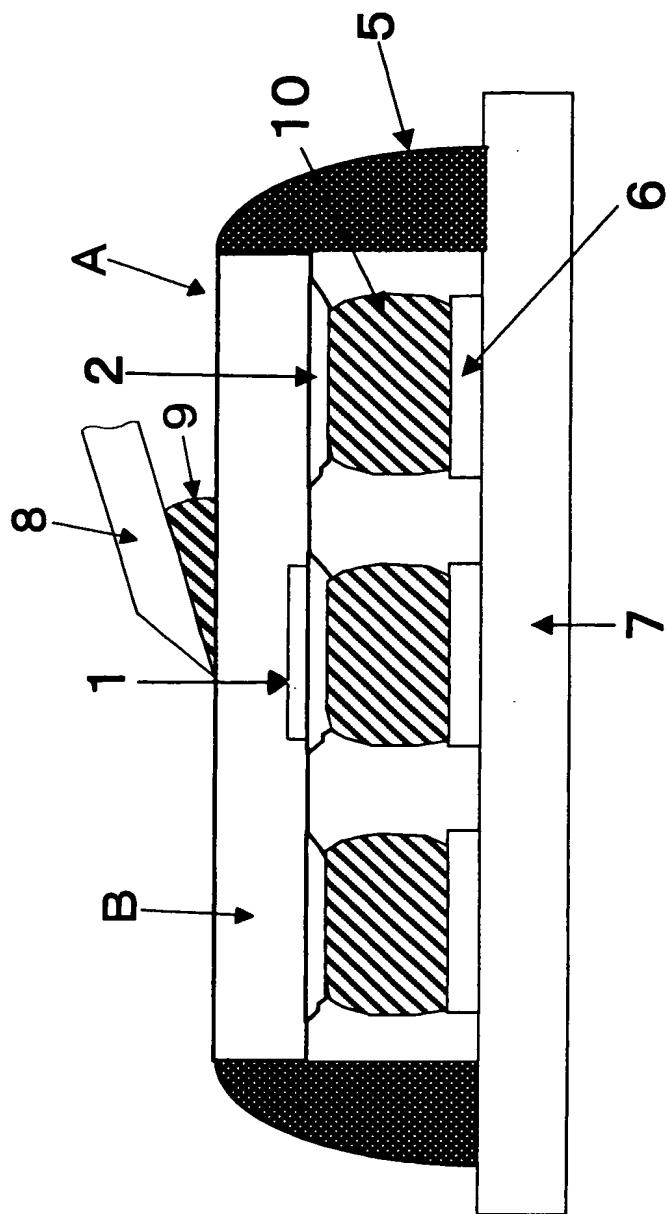
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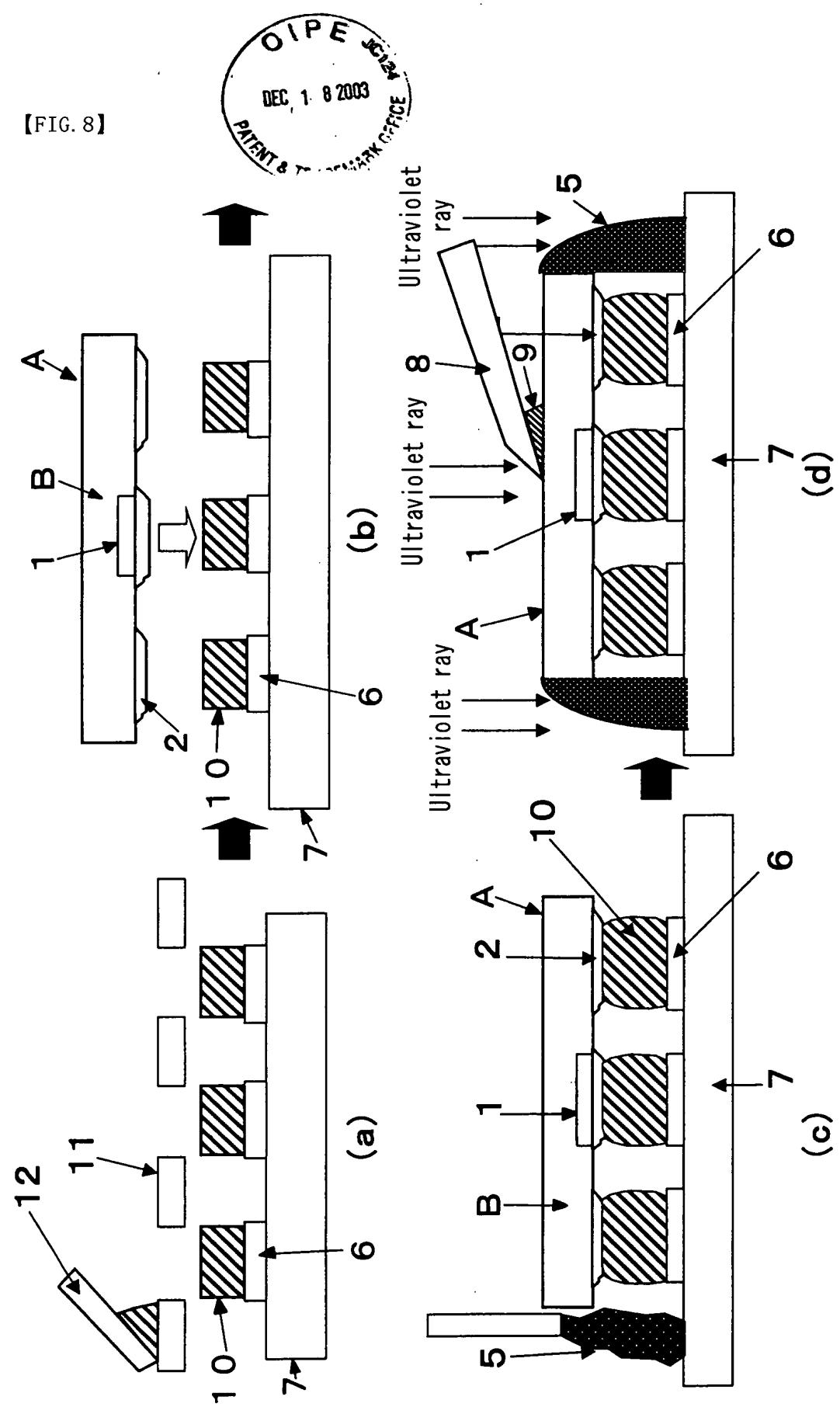
[FIG. 6]



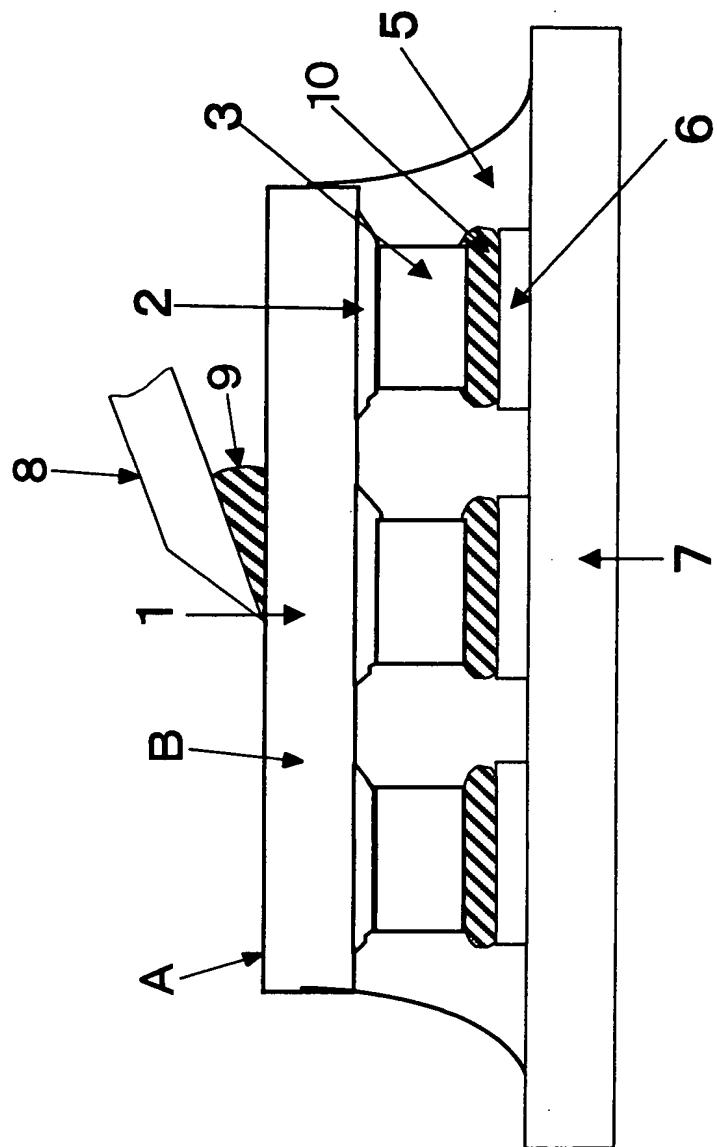
[FIG. 7]



[FIG. 8]

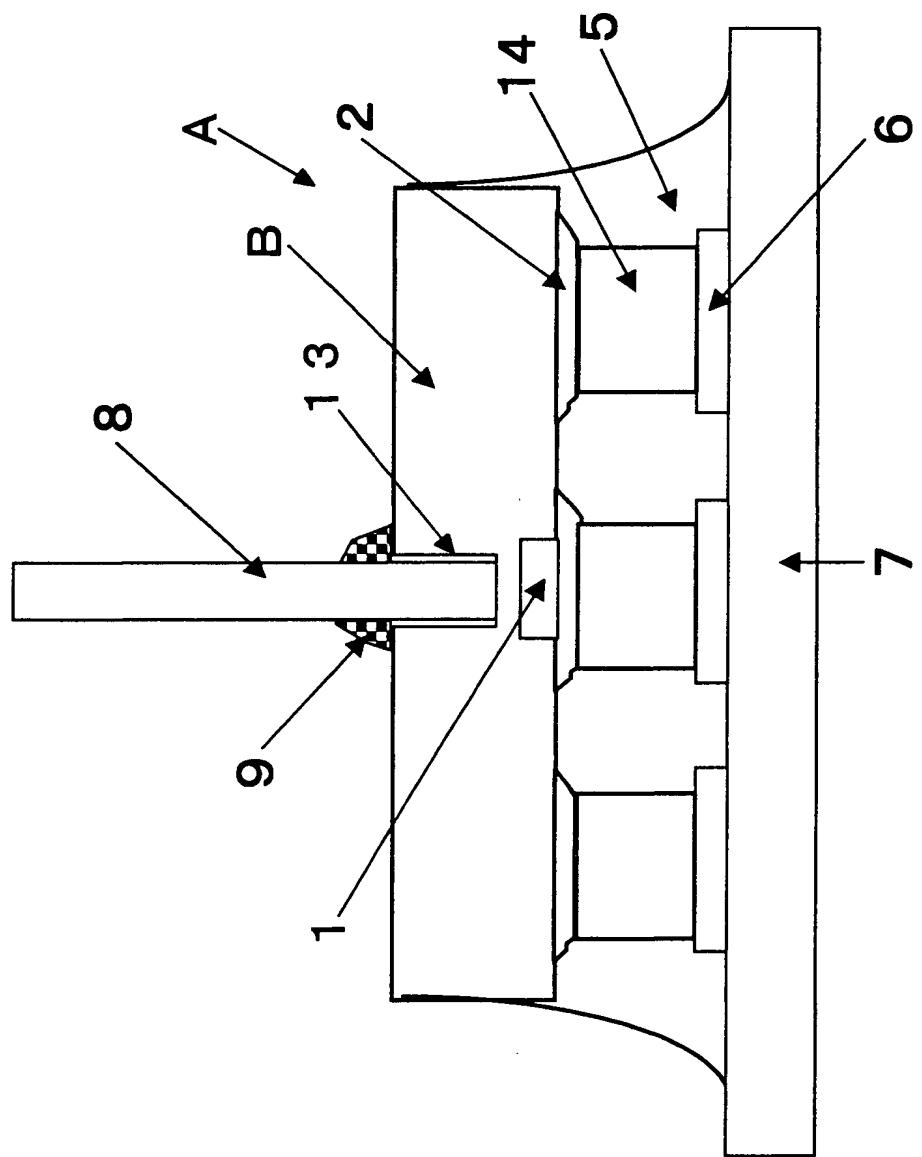


【FIG. 9】

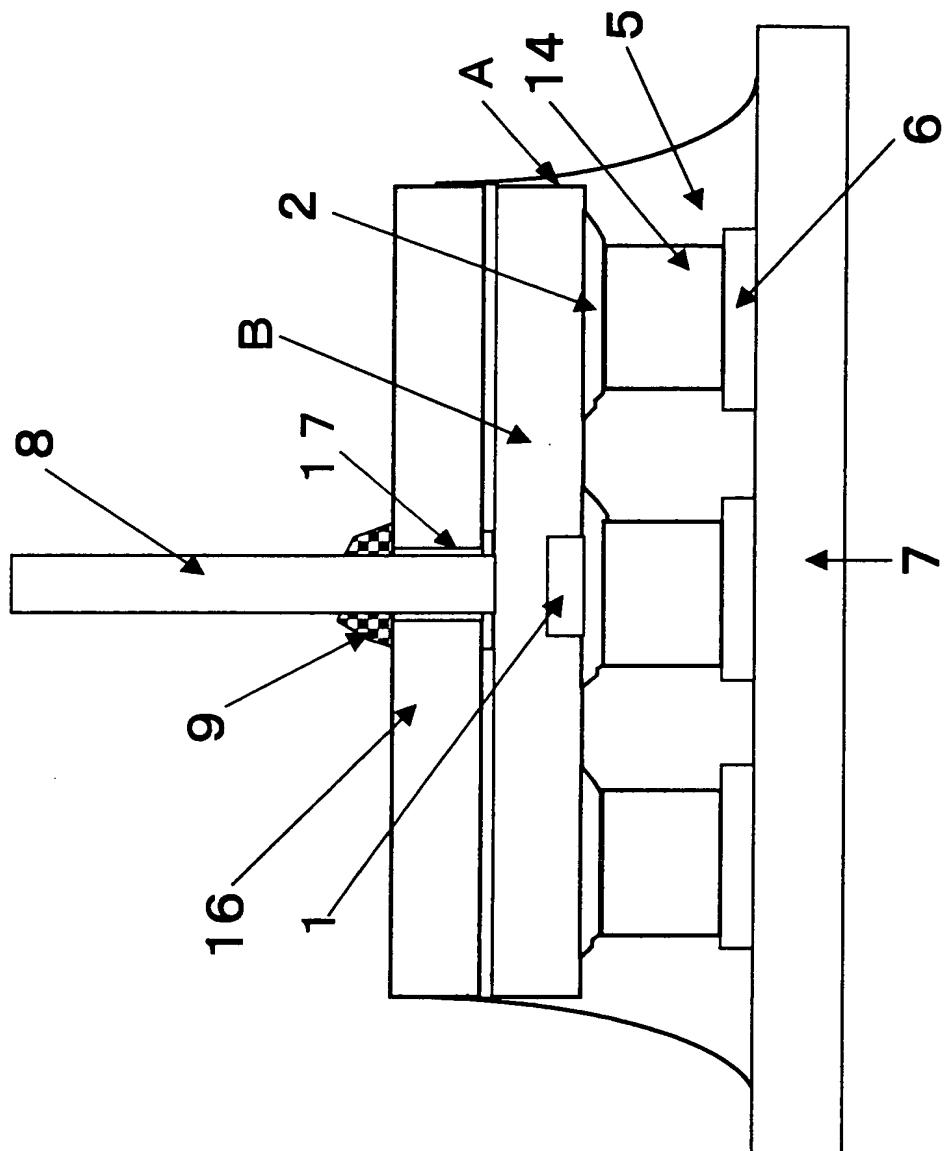


[FIG. 10]

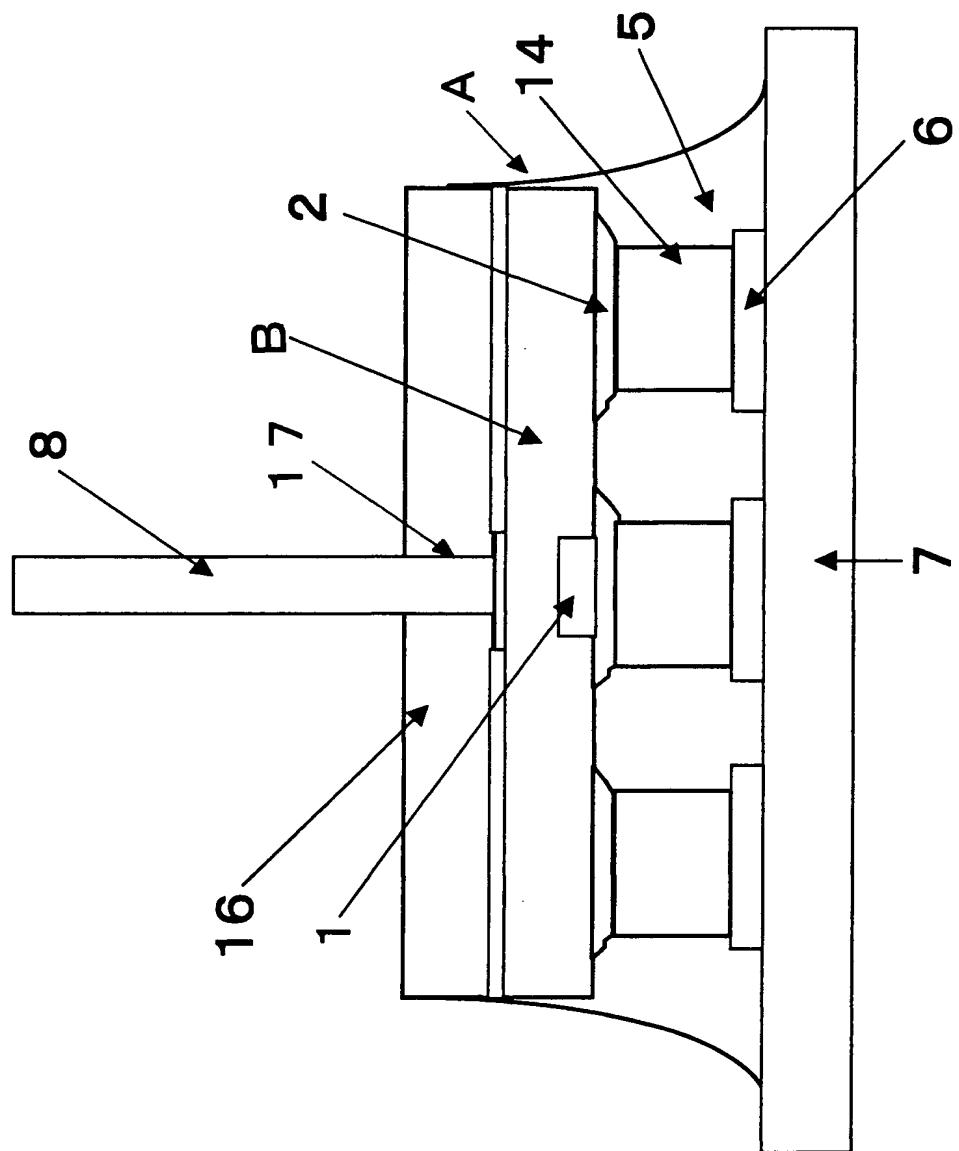
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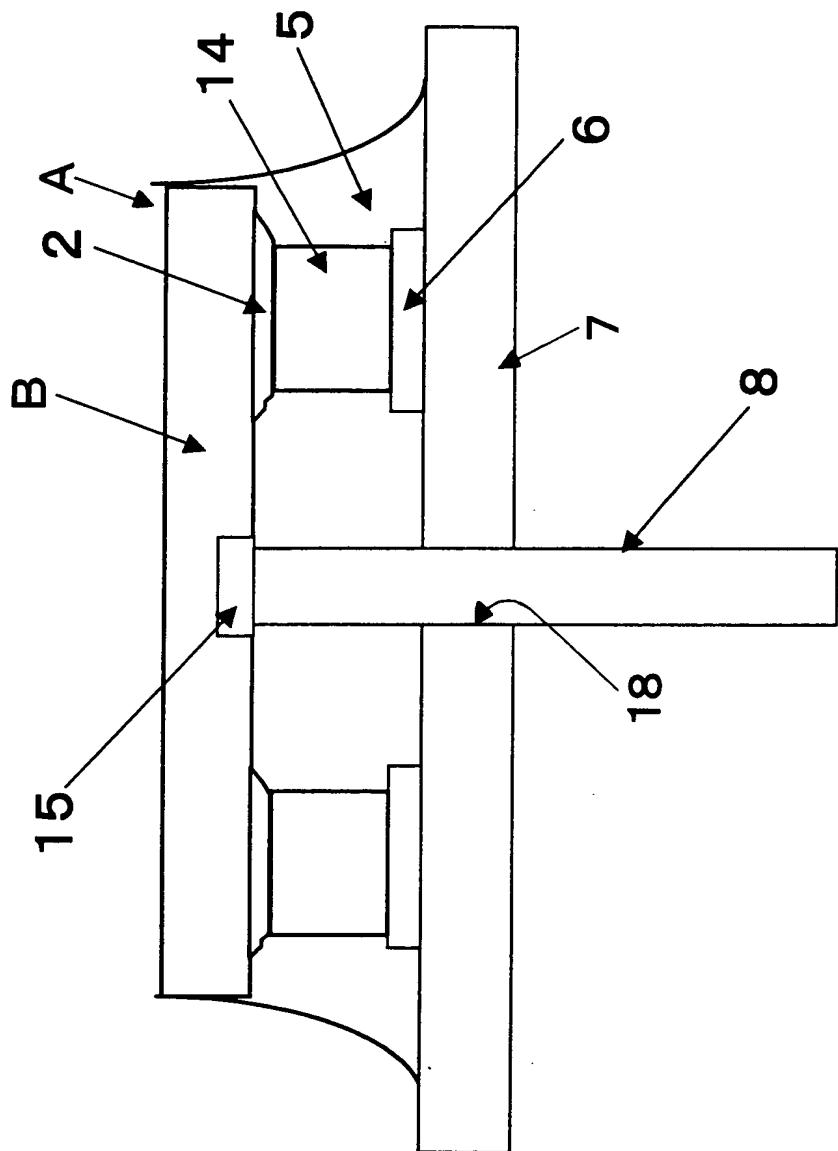
【FIG. 11】



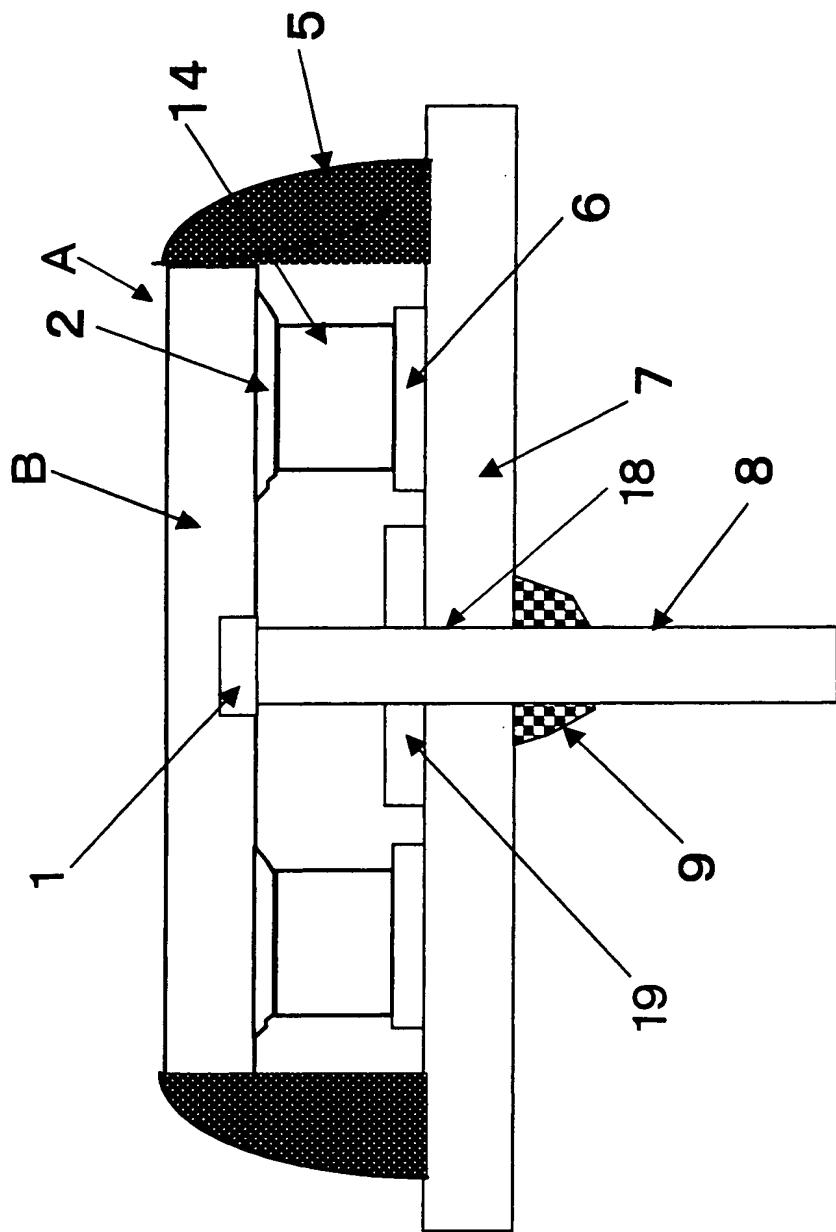
【FIG. 12】



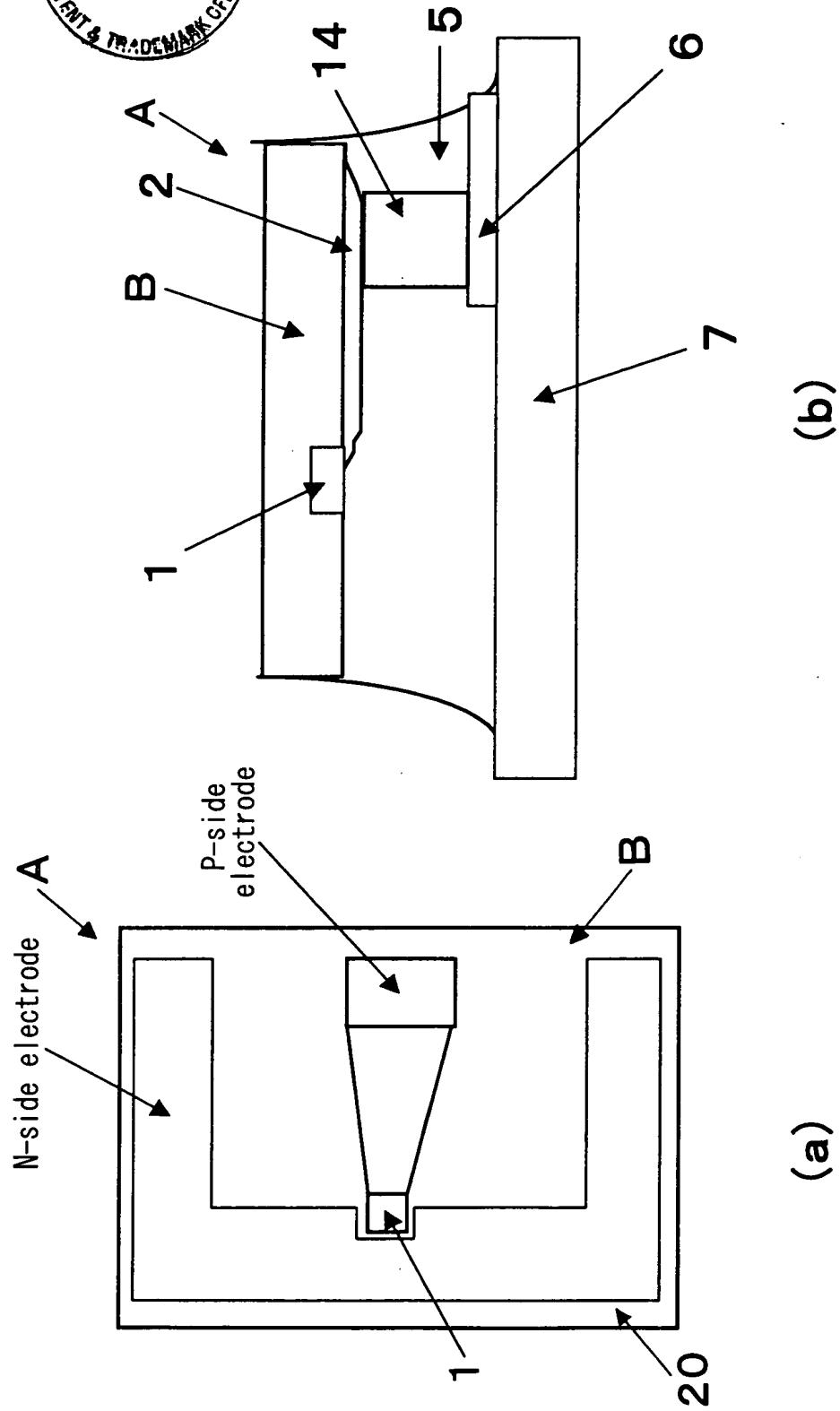
[FIG. 13]



【FIG. 14】



【FIG. 15】



[FIG. 16]

